A 60GHz Passive Repeater with Endfire Radiation Using Dielectric Resonator Antennas

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***Abstract* — This paper presents the design of a 60GHz passive repeater endfire array using dielectric resonator antenna (DRA) elements. The proposed DRA antenna element is loaded with an open-ended microstrip line coupled through a slot, and the reflection phase is controlled by varying the length of this phase-delay line. Based on the working principle of reflectarray, two DRA elements with 180° phase difference are selected with the aid of infinite periodic simulation model in HFSS. A 6x6 array is designed and simulation results demonstrate good endfire performance.**

***Index Terms* — 60GHz, passive repeater, endfire array, microstrip stub-slot loaded, dielectric resonator antenna.**

I. Introduction

Endfire antenna arrays play an important role in communication and radar [1]. Microstrip patch arrays with ground plane do not easily provide endfire radiation due to the cancellation effect resulting from mirror image currents. Artificial magnetic conductors (AMC) or high impedance surfaces (HIS) have been proposed [2] as an effective solution for backing microstrip endfire arrays. However they result in a quite complicated design and usually exhibit a reduced bandwidth.

The specific problem of planar reflecting surfaces with endfire radiation is even more complex. In that case, the considered surface has to comply with two constraints: *i*) it must provide a full reflection of the incident wave (thus requiring a ground plane) and *ii*) it must produce a radiation parallel to the surface. Such a configuration may be encountered in passive repeaters [3] for indoor communications.

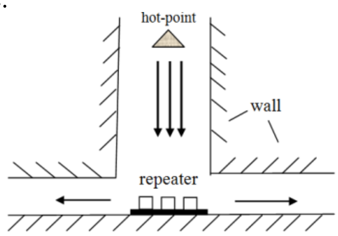


Fig. 1. Typical passive repeater relay in T-shape corridor.

A typical situation is illustrated in Fig. 1, where a passive repeater aims at illuminating a T-shaped corridor by redirecting the incident wave from a single 60GHz hot-point in the orthogonal direction.

In this paper, we propose to solve this problem by means of a passive repeater made of DRAs. For a conveniently chosen radiating mode, a DRA radiates like a magnetic dipole and can thus be backed by a ground plane. DRAs are also particularly well suited for millimeter waves due to their intrinsic low loss [4]. Moreover, they naturally exhibit a quite large bandwidth. In this communication, an array of DRAs is used to provide endfire re-radiation when illuminated by a normally-incident plane wave. To do so, successive elements with $\lambda_0/2$ spacing are slot-coupled to open microstrip lines providing out-of-phase reflection. In section II, the design of the DRA phase-shifting element is derived to comply with the requirements of the problem presented in Fig 1. In section III, a 6x6 array is simulated and its performance is compared to that of a simple corner reflector.

II. Design of the Phase-Shifting DRA

A. General Antenna Configuration

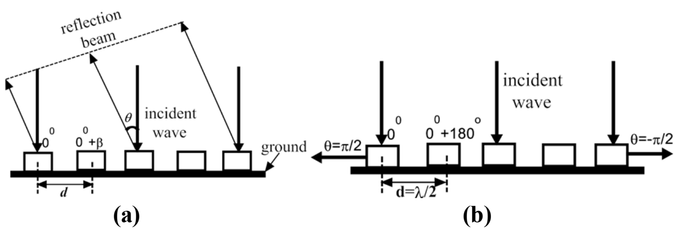


Fig. 2. (a) General working principle for passive repeater array based on DRA, (b) Proposed implementation for combined endfire/backfire radiation.

Fig.2 illustrates the typical foreseen configuration where DRA elements are regularly disposed over a ground plane and illuminated by an impinging plane wave under normal incidence. It is assumed this wave is produced by a remote source and the aim of the DRA reflector is to re-direct it at both endfire and backfire, as shown in Figure.1. This configuration is quite similar to that of a reflectarray: a prescribed phase-shift has to be applied to the successive DRA elements to scan the reflected beam in the desired direction.

Typically, for a beam in θ direction, the phase difference β between two successive elements should meet equation:

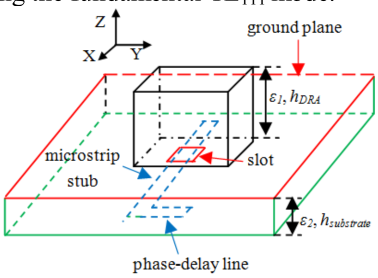
$$\beta = k_0 d \sin\theta \quad (1)$$

in which k_0 stands for the wave number and d for the inter-element spacing. Endfire and backfire radiation ($\theta = \pm\,\pi/2$) can be achieved with out-of-phase elements (β=π) by using a half wavelength inter-element spacing (d= λ/2).

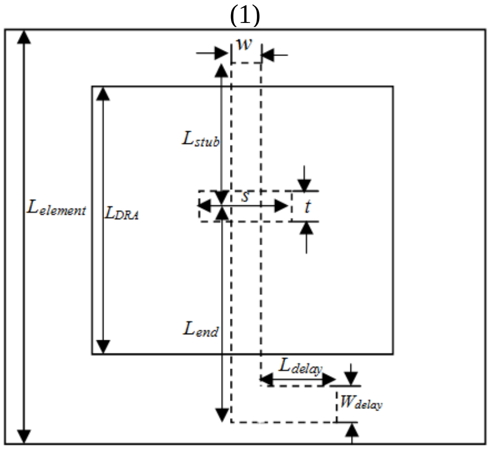
B. DRA element design

In the proposed structure, the phase reflected by a DRA is tuned by varying the length of an open-ended microstrip line coupled to the element through a slot (as done in [5] for patches). Other phase-shifting techniques could have been used, as modifying the size of the DRA itself [6]. However, in that case, for at least one of the phase-shifts, the DRA element would be used out of its resonant frequency which means most of the incident power would be reflected by the ground plane itself and directed in the specular direction (at broadside). This would be inappropriate for endfire radiation.

As shown in Fig.3, the selected DRA has a rectangular shape, which offers simple design and magnetic dipole operation using the fundamental TE_{111} mode.



(1)



(2)

Fig. 3. DRA element design: (1) semi-sectional view, (2) top view; ε_1=10, ε_2=4.4, h_{DRA}=0.52mm, $h_{substrate}$=0.15mm, $L_{element}$=2.5mm, L_{DRA}=1.2mm, L_{end}=0.8mm, L_{stub}=0.875mm, s=0.79mm, t=0.37mm, w=0.28mm, W_{delay}=0.2mm.

As a first step of the design, the dimensions of the DRA element are optimized to achieve a 60 GHz resonant frequency. The dimensions of the stub and of the slot are tuned for a good matching between the DRA and the line. All the simulations are performed using Ansoft HFSS 13.0. Fig. 4 presents the reflection coefficient on the DRA for an incident plane wave when the microstrip line is loaded with a matched load. It shows that all the incident power is captured by the DRA and transferred to the line, at 60 GHz.

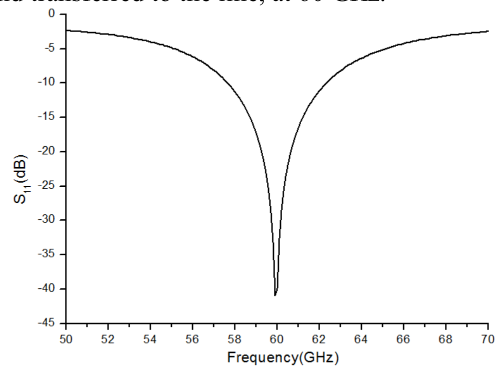


Fig. 4. S_{11} for DRA element loaded with matched microstrip stub.

For the next step, the matched load is replaced by an open circuit. By varying the length of phase-delay line L_{delay}, the phase of the reflected wave can thus be tuned, as shown in Fig. 5. In the meantime, the magnitude of the reflection coefficient is higher than -1dB which guarantees that almost all the incident power is reflected back (except from losses in the dielectric material whose loss tangent is 0.02).

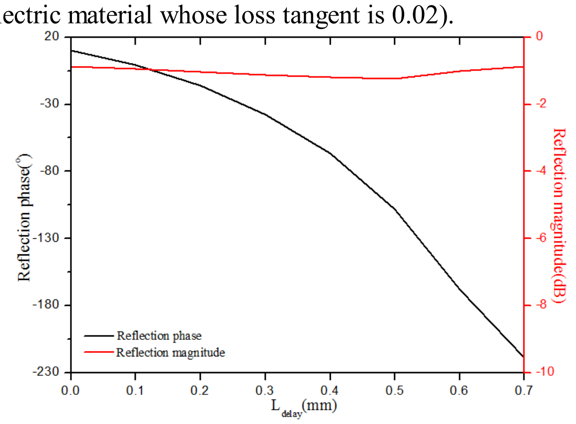


Fig. 5. Phase and magnitude of the reflection coefficient when L_{delay} varies from 0.1mm to 0.7mm.

As discussed before, only two different phase-shifts with a π separation are required. So based on Fig.5, the corresponding lengths L_{delay} could be chosen as L1=0.4mm and L2=0.7mm.

It should be mentioned that these simulations have been carried out assuming local periodicity by simulating a single cell extracted from an infinite periodic array. In the final array, two consecutive elements will be out-of-phase, which means the local periodicity assumption is not very realistic in our case. In order to better approximate the actual mutual coupling between consecutive elements, L1 and L2, will have to be re-optimized as explained in the next section.

III. ARRAY SIMULATION AND OPTIMIZATION

A 6x6 array is designed and simulated to demonstrate the capability of the proposed structure. As depicted in Fig.6, the 6x6 array is placed in the X-Y plane and excited by the X-polarized incident wave. The π phase-shifting is applied in the E-plane so that null radiation is expected in the z direction and maximum along the x-axis.

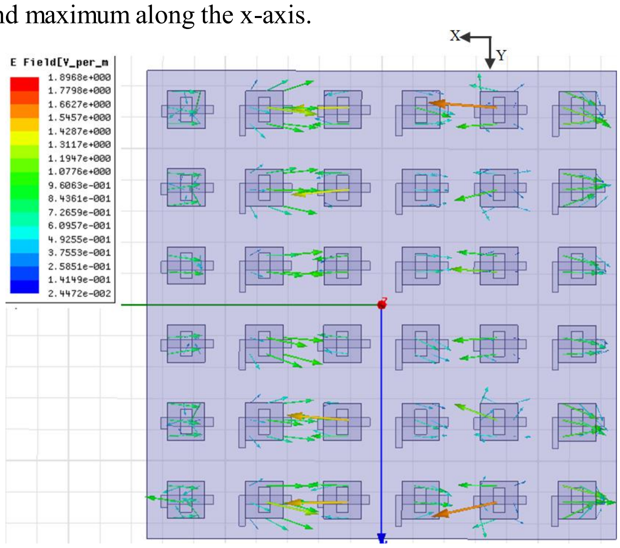


Fig. 6. E-field distribution of 6x6 DRA endfire array.

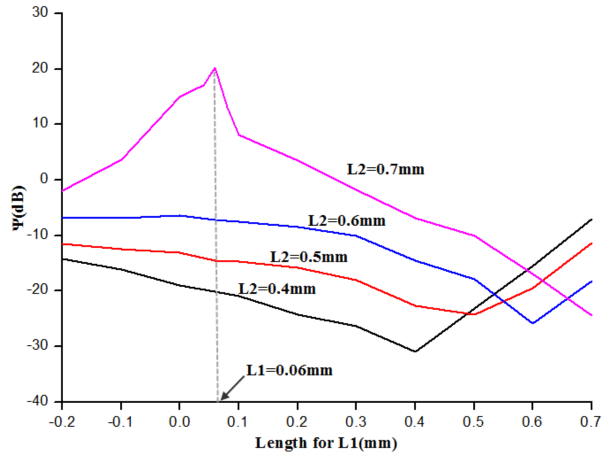


Fig.7. Re-optimization for L1and L2 with parameter ψ.

In order to evaluate the endfire array's radiation performance, we define $\psi=\left|E(\pm\pi/2)\right|/\left|E(0)\right|$, which stands for the difference value between array's radiation fields in $\pm\pi/2$ and 0 directions, in the E-plane. Clearly, a high ψ promises a good endfire radiation.

As seen in Fig.7, the best performance is obtained for L1=0.06mm and L2=0.7mm. The difference between L1 and L2 is larger than the one obtained from Fig. 5 and only L2=0.7 mm permits to reach values of ψ larger than 0dB. Logically, ψ is minimum for L1=L2.

Fig.8 presents the front radiation of the structure (E-plane for θ varying from -90° to 90°). A clear comparison is taken on the performance of the proposed repeater with a corner reflector and a reference metal plane (all having the same horizontal surface). Both the corner reflector and the DRA array provide endfire radiation. The main interest of the DRA array is its low profile.

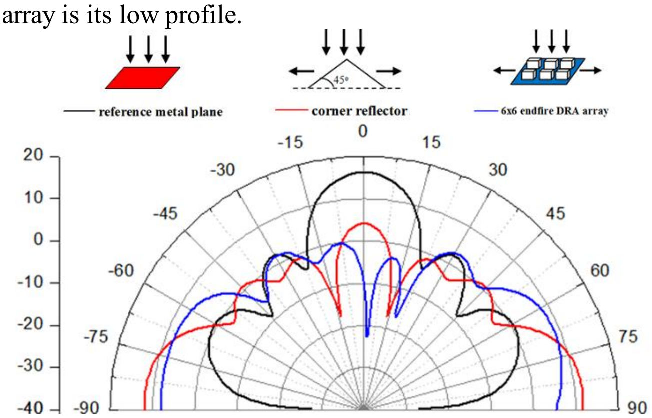


Fig.8 Co-polarization E-plane pattern for 6x6 array and two groups of comparison with different metal ground.

IV. Conclusion

A novel DRA passive repeater endfire array at 60GHz is proposed in this paper. The DRA element uses a microstrip phase-delay line to control the reflection phase with only two different lengths of the phase-delay line. A 6x6 array is designed and simulated. The results demonstrate good endfire performance.

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